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Measurement of surface figure of plane optical surfaces with polarization phase-shifting Fizeau interferometer

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Abstract

A Fizeau interferometer based set up for measurement of surface forms of plane optical surfaces has been discussed. Phase shifting interferometry has been applied using polarization phase shifter. A linearly polarized (632.8 nm) He–Ne laser has been used as the source. Light reflected from the object and the reference/master surfaces are made circularly polarized in opposite senses by means of two properly oriented quarter wave retardation plates placed at appropriate positions, one inside and other outside the interference cavity of the interferometer, and phase shifts are introduced between the object and the reference/master waves by varying angular orientation of a polarizer/analyzer. Final result is made free from any residual wave-front aberrations introduced by the (intra-cavity) wave plate by subtracting phase values obtained by PSI technique between a high optical quality master surface and the reference surface from that obtained for the test object surface with respect to the same reference surface for each point of the interference field. Results are shown for a plane surface.

Advantages of the technique presented are linearity and high accuracy in phase stepping, no perturbation of the interference cavity during the phase shifting and possibility of real time or dynamic interferometry.

Keywords: Fizeau interferometer; Surface figure; Phase shifting interferometry

1. Introduction

Fizeau interferometers (FI) [1,2] are most commonly used for testing of surface figure, flatness, parallelism, homogeneity, etc of optical components. In FI, the optical path difference (OPD) between the test and the reference wave cannot be made zero and the interferometer is most suitable with a coherent source, such as laser, although quasi-monochromatic sources can also be used [2]. FIs are not exactly common path interferometers but the interfering beams travel nearly identical paths. For this reason, compared to Twyman–Green interferometer, FI systems are less susceptible to external mechanical vibrations and the measurements are much less affected by aberrations of the interferometer systems.

Phase shifting interferometry (PSI) [3–6] has been extensively used for accurate quantitative evaluation of phase information using FIs [7–9]. Most common methods of introducing phase shifts or modulation are available in literature [10,5, pp. 296–300, 6, pp. 506–510]. Accuracy of PSI technique, sources of errors, susceptibility and sensitivity of different algorithms, techniques of reduction of errors and calibration of phase shifter have been discussed in details in reports [11–17,4, pp. 373–374, 6, pp. 536–546].

Present paper describes a polarization phase shifting [18–26] Fizeau interferometer for measurement of surface flatness of plan–optical surfaces.

2. Principle

Optical schematic of the Fizeau interferometer based set up for measurement of surface figure of plane optical surfaces is shown in Fig. 1. Light from a linearly polarized

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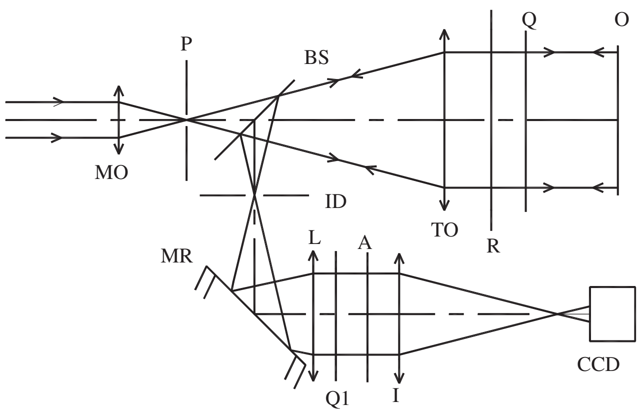

Fig. 1. Optical schematic of the Fizeau interferometer based set up.

He–Ne (632.8 nm) laser source is allowed to pass through a spatial filtering arrangement consisting of a microscope objective (MO) and an appropriate pinhole (P) placed at the front focal point of the microscope objective. The pinhole is also situated at the back focal plane of a well corrected telescope objective (TO) and thus a linearly polarized, expanded collimated beam is produced. Fizeau interferometer cavity is formed between the uncoated front surface (R) (surface adjacent to the test surface) of a high optical quality transparent plane reference plate of fused silica and the test object surface (O). The reference plate is wedged ($\sim 0.5^\circ$) to eliminate the effect of unwanted Fresnel reflections from its rear surface, which is anti-reflection coated. The plane reference plate and the test object are mounted on high quality tip-tilt mirror mounts. Beams reflected from the reference and the test surfaces interfere to form two beam Fizeau fringes. To introduce polarization phase shift between the interfering beams, the direction of polarization of the beam reflected from the object surface is rotated by means of a quarter wave plate (QWP), (Q) placed in the Fizeau cavity with its axes at 45° with the direction of polarization of the incident collimated beam from TO. The incident collimated beam after passing through Q becomes circularly polarized and after reflection at the object surface and double passing through Q, the beam becomes linearly polarized in orthogonal direction with that of the beam reflected from the reference surface R. Polarization maintaining beam splitter (BS) directs these beams towards a folding mirror (MR). The iris diaphragm (ID) placed at the rear focal plane of the telescope objective blocks unwanted light. The beams are then collimated by lens L whose rear focal point coincides with that of the telescope objective TO. These beams which are linearly polarized in orthogonal directions are made circularly polarized (left and right circular polarizations) by a quarter wave plate (Q1) placed with its axes at 45° to the directions of polarizations of the linearly polarized orthogonal beams. An analyzer (A) placed after the quarter wave plate Q1 selects linear components from the circularly polarized beams along its pass directions. These linear components interfere to produce two beam Fizeau fringes. Fizeau fringes are grabbed by means of a CCD Camera, Frame grabber and PC arrangement. The test object plane is imaged on the CCD plane by means of the imaging lens I.

We can see from the following considerations that it is possible to introduce phase shifts between the interfering components by changing the angular position of the analyzer A (in its plane).

Jones vectors for linearly polarized light with direction of polarization in the vertical and horizontal directions can be written as

$$E_v = \begin{bmatrix} 0 \\ 1 \end{bmatrix} \quad \text{and} \quad E_h = \begin{bmatrix} 1 \\ 0 \end{bmatrix},$$

respectively.

Jones matrix for the QWP with its fast axis at an angle 45°. with horizontal direction is given by

$$D = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 & i \\ i & 1 \end{bmatrix}.$$

After passing through the QWP (Q1), the vertically polarized beam will become

$$E_1 = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 & i \\ i & 1 \end{bmatrix} \begin{bmatrix} 0 \\ 1 \end{bmatrix} = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 \\ -i \end{bmatrix} \mathrm{e}^{\mathrm{i}\Pi/2},$$

which is a left circularly polarized light and the horizontally polarized light will become,

$$E_2 = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 & i \\ i & 1 \end{bmatrix} \begin{bmatrix} 1 \\ 0 \end{bmatrix} = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 \\ i \end{bmatrix},$$

which is a right circularly polarized light.

Jones Matrix of an analyzer with its pass axis at an angle θ with the horizontal direction can be represented by

$$A(\theta) = \begin{bmatrix} \cos^2\theta & \cos\theta\sin\theta \\ \cos\theta\sin\theta & \sin^2\theta \end{bmatrix}.$$

When the circularly polarized components (E_1 & E_2) pass through the analyzer placed with its axis at an angle θ with the horizontal, the transmitted components (E_1^1, E_2^2) through the analyzer are given by

$$\begin{aligned} E_1^1 &= A(\theta)E_1 \\ &= \frac{1}{\sqrt{2}} \begin{bmatrix} \cos^2\theta & \cos\theta\sin\theta \\ \cos\theta\sin\theta & \sin^2\theta \end{bmatrix} \begin{bmatrix} 1 \\ -i \end{bmatrix} \mathrm{e}^{\mathrm{i}\Pi/2} \\ &= \frac{1}{\sqrt{2}} \begin{bmatrix} \cos\theta \\ \sin\theta \end{bmatrix} \mathrm{e}^{-\mathrm{i}(\theta-\Pi/2)}, \end{aligned} \tag{1}$$

$$\begin{aligned} E_2^1 &= A(\theta)E_2 \\ &= \frac{1}{\sqrt{2}} \begin{bmatrix} \cos^2\theta & \cos\theta\sin\theta \\ \cos\theta\sin\theta & \sin^2\theta \end{bmatrix} \begin{bmatrix} 1 \\ i \end{bmatrix} \\ &= \frac{1}{\sqrt{2}} \begin{bmatrix} \cos\theta \\ \sin\theta \end{bmatrix} \mathrm{e}^{\mathrm{i}\theta}, \end{aligned} \tag{2}$$

respectively.